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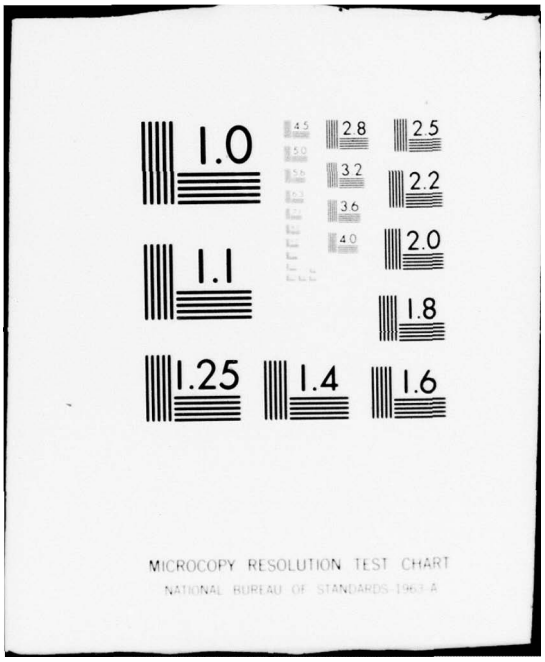
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The Nature of Mental Abilities

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A theory of the nature of mental abilities is presented. In this theory, mental abilities are hierarchically organized into four progressively deeper levels--the levels of composite tasks, subtasks, information-processing components, and information-processing metacomponents. Composite tasks can be decomposed into subtasks, subtasks into components. Metacomponents control the use of components in composite tasks and subtasks. Each of the four levels of mental abilities is described and interrelated to

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the others. The fundamental theoretical questions relevant at each level are posed, and answers to these questions are proposed. The role of factors in the theory is described, and is shown to be quite different from the role of factors in traditional theories of mental abilities. Full understanding of mental abilities requires understanding of all four levels.

The Nature of Mental Abilities

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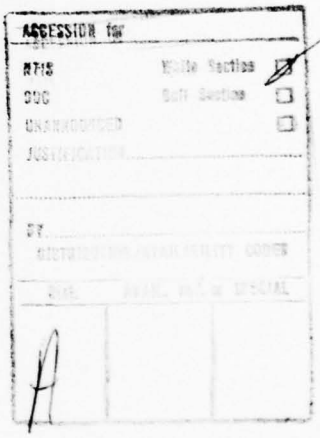

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Abstract

A theory of the nature of mental abilities is presented. In this theory, mental abilities are organized into four levels--the levels of composite tasks, subtasks, information-processing components, and information-processing metacomponents. Composite tasks can be decomposed into subtasks and subtasks into components. Metacomponents control the use of components in composite tasks and subtasks. Each of these levels of mental abilities is described. The fundamental theoretical questions relevant at each level are posed, and answers to these questions are proposed. The role of factors in the theory is described, and is shown to be quite different from the role of factors in traditional theories of mental abilities. Full understanding of mental abilities requires understanding of all four levels.

The Nature of Mental Abilities

Psychologists and laymen alike have puzzled for years over the structure and content of mental abilities. Structure refers to the form or forms mental abilities take, and to the way in which these abilities are organized. Are they processes, strategies, drives, habits, nerve impulses, some combination of these, or some other kind of entity? Can they be characterized in terms of some kind of linear, circular, hierarchical or other organization? Content refers to the identities of the processes, strategies, drives, or whatever. Knowledge of content presupposes knowledge of structure, since the structure of mental abilities delimits the possible contents of these abilities: Structure determines the form the list of mental abilities will take.

This article seeks to address the issues of both the structure and content of mental abilities. The theory I propose comprises four levels of ability. The four sections of this article that follow describe each of the four levels. A fifth section describes how each of the four levels can be perceived from an alternative point of view. The sixth, final section summarizes the material that precedes it. The presentation in this article follows Figure 1, which shows the structure and some of the content of the theory.

Insert Figure 1 about here

Four Levels of Mental Ability

The Level of Composite Tasks

The first level of the theory is that of the composite task--the full task as the subject sees it. From the standpoint of a theorist

of mental abilities, the most important question at this level deals with task selection: What tasks should we use in the assessment of mental abilities? In order to answer this question, we need criteria for deciding what tasks merit inclusion in an assessment battery. There is no consensus as to what these criteria should be. I propose four criteria, however, that have proven valuable in the evaluation of alternative measures of a construct in memory theory called subjective organization (Sternberg & Tulving, 1977). The four criteria are the following:

1. Quantifiability. Performance on the task must be susceptible to bona fide measurement, that is, the "assignment of numerals to objects or events according to rules" (Stevens, 1951, p. 1).

2. Reliability. Performance on the task must demonstrate a high degree of consistency, or true-score variation relative to observed-score variation (Lord & Novick, 1968). If an individual's performance fluctuates wildly--either because judges cannot agree on what constitutes a certain level of performance, or because the task does not lend itself to stable performance--then the task is not useful as a measure of mental ability.

3. Construct validity. Construct validity, "the degree to which a test measures the construct it was designed to measure" (Lord & Novick, 1968, p. 278), requires that inclusion of a task or test in a battery measuring mental abilities be dictated by some prior theory regarding the identification of these abilities via tasks or tests.

4. Empirical validity. Empirical validity, "the degree of associa-

tion between the measurement and some other observable measurement" (Lord & Novick, 1968, p. 261), requires that the task or test included in a battery be predictive of performance in some other task or test (criterion) that is alleged to require the same mental ability or abilities (either alone or in combination with other abilities).

My choice of tasks has been guided by an evolving subtheory of intelligence that I call the unified componential theory of human reasoning (Sternberg, Note 1). This theory will be described in more detail later. According to the theory, reasoning, a major aspect of intelligence (see Sternberg, 1977b, Chapter 13), comprises a relatively small number of information-processing components. Various combinations of these components are required in the solution of problems used to measure reasoning ability in standard tests of intelligence.

My colleagues and I have investigated the performance of adults in a variety of inductive and deductive reasoning tasks, including (among others) the following:

1. Analogies (Sternberg, 1977a, 1977b; Sternberg & Rifkin, in press; Sternberg & Gardner, Note 2; Sternberg & Nigro, Note 3). In a typical analogies task, the subject is given the first three terms of an analogy and a blank term, such as LAWYER : CLIENT :: DOCTOR : ____, and is asked which of two terms, for example, (a) MEDICINE, (b) PATIENT, better completes the analogy.

2. Classifications (Sternberg, Note 4; Sternberg & Gardner, Note 2). In one variant of the classification task, the subject is presented with three terms and a blank term, such as LEAF, TRUNK, ROOT, ___, and is asked which of two terms, such as (a) BRANCH, (b) TREE, belongs in the

same class as the first three terms.

3. Series completions (Sternberg, Note 4; Sternberg & Gardner, Note 2). In one form of series completion problem, the subject receives three terms that form a series, and a blank term, for example, TRUMAN, EISENHOWER, KENNEDY,_____, and must decide which of two terms, such as (a) JOHNSON, (b) ROOSEVELT, better completes the series.

4. Linear syllogisms (Sternberg, Guyote, & Turner, in press; Sternberg, Note 5; Sternberg, Note 6). In problems of this type, subjects receive two premises, such as JOHN IS TALLER THAN PETE; PETE IS TALLER THAN BILL, and a question, such as WHO IS TALLEST? The subjects must respond with the name of one of the three individuals mentioned in the premises.

5. Categorical syllogisms (Sternberg, Guyote, & Turner, in press; Guyote & Sternberg, Note 7; Sternberg & Turner, Note 8). In one form of categorical syllogism, subjects receive two premises, such as ALL B ARE C; ALL A ARE B, and a conclusion, such as ALL A ARE C. The subjects must indicate whether the conclusion follows logically from the premises.

6. Conditional syllogisms (Sternberg, Guyote, & Turner, in press; Guyote & Sternberg, Note 7). In a typical conditional syllogism, subjects receive two premises, such as IF A THEN B; A, and a conclusion, such as B. The subjects must indicate whether the conclusion follows logically from the premises.

Problems such as these satisfy the four criteria described earlier for inclusion in a battery of tasks measuring mental abilities. Performance on each task is quantifiable in terms of response times to

solution and error rate in solution. The tasks have been demonstrated to yield reliable performance, with reliability coefficients usually exceeding .90. The tasks demonstrate construct validity, in that their selection has been guided by the unified componential theory of human reasoning, according to which performance on each of these tasks can be decomposed into a small number of basic information-processing components that overlap across tasks and that are fundamental to understanding reasoning, and hence intelligence. And the tasks have been shown to be empirically valid indicators of mental abilities as measured at the level of the composite task: Performances on these tasks are correlated with each other, with performance on standard intelligence tests, and with school performance.

Why do we need levels of analysis deeper than the level provided by the analysis of composite tasks? There are at least three reasons. First, a mere listing of tasks and subjects' scores on them is theoretically barren. It gives us no understanding of the determinants of performance on the tasks: The representations of information, the processes that act upon these representations, and the strategies by which these processes are combined are left unspecified. Second, the number of possible tasks seems without limit. What constitutes a distinct task, and what a trivial variant of a task? Two tasks may appear to be quite different on the surface, and yet require quite similar processes or strategies in their solution; obversely, two tasks may appear to be quite different on the surface, and yet require quite similar processes or strategies in their solution. Without a theoretical analysis of

performance on the tasks, we have no basis for stopping an endless proliferation of "new" tasks. Third, performances on these and other tasks are correlated both across subject and across task manipulations. For example, subjects who perform well on the categorical-syllogisms task tend to perform well on the conditional-syllogisms task; moreover, when certain types of categorical and conditional syllogisms are paired on the basis of structural similarities, high performance on one member of the pair is associated with high performance on the other member of the pair. All of these considerations suggest the need for a deeper level of analysis. We want, somehow, to break down task performance into smaller chunks that may be common across tasks. A first step in this breakdown is to decompose tasks into subtasks.

The Level of Subtasks

Most tasks, and indeed, all of the tasks that my collaborators and I have investigated, can be decomposed into subtasks, where a subtask is defined in terms of its involvement of a subset of the information-processing components that are involved in the full task. There are a number of reasons for attempting to isolate information-processing components from subtasks rather than from composite tasks. First, it is often possible to isolate information-processing components from subtasks that cannot be isolated from composite tasks. The smaller the number of information-processing components involved in any single subtask, the greater is the likelihood that the individual components will be susceptible to isolation. Second, use of subtasks requires the investigator to specify in which subtask(s) each information-processing component is executed, and thus requires tighter, more nearly complete

specification of the relationship between task structure and the components that act upon that structure. Third, use of subtasks increases the number of data points to be accounted for, and thus helps guard against the spurious good fit between model and data that can result when the number of parameters to be estimated becomes large relative to the number of data points to be predicted. Fourth, use of subtasks results in component-free estimates of performance for a series of nested processing intervals. These estimates can be valuable when one wants to test alternative predictions about global stages of information processing (see example below). Although the use of subtasks is not always necessary (see, for example, Guyote & Sternberg, Note 7), I have found subtasks informative whenever I have used them, and it is always possible to test whether their use changes the nature of the task (see Sternberg, 1977b). The decomposition of composite tasks into subtasks, then, represents a useful intermediate step in the analysis of the nature of mental abilities.

Composite tasks can often be decomposed into subtasks in a variety of different ways and by a variety of different methods (enumerated in some detail in Sternberg, in press [a]). How might the tasks described earlier be decomposed? Let us consider the tasks in two groups, the induction tasks (analogies, classifications, and series completions) and the deduction tasks (linear syllogisms, categorical syllogisms, and conditional syllogisms):

1. Induction tasks. I have generally decomposed induction tasks via the method of precueing (Sternberg, 1977b, in press [a]). In this

method, presentation trials are divided into two parts, the first of which consists of precueing that facilitates problem solution, and the second of which consists of the full problem and thus allows problem solution. In the first part of the trial, the subject processes the precueing information as fully as possible, and then presses a button or in some other way indicates readiness to see the full problem; in the second part of the trial, the subject solves the problem. The precueing consists of the first k terms of the problem, where k varies across conditions of precueing, and ranges between zero and the number of terms in the problem. Consider, for example, the analogy, LAWYER : CLIENT :: DOCTOR : (a) MEDICINE, (b) PATIENT. The subject might receive as precueing either zero terms (a blank field), one term (LAWYER), two terms (LAWYER : CLIENT), three terms (LAWYER : CLIENT :: DOCTOR), four terms (LAWYER : CLIENT :: DOCTOR : (a) MEDICINE), or five terms (LAWYER : CLIENT :: DOCTOR : (a) MEDICINE, (b) PATIENT). Note that the first and last conditions are "degenerate" conditions of precueing, in that the precueing supplies either no information, or full information. In the method of precueing, both the first (precueing) and second (solution) parts of the trial involve subtasks, although it is usually the second part of the trial that is of primary interest. The same kind of task breakdown can be applied to the classification and series problems described earlier. In each type of problem, there are five terms, and thus five possible conditions of precueing. Usually, one will not use all possible conditions, because one wants to select only those conditions of precueing that (a) do not alter the strategy by which subjects

solve the problems, and (b) actually facilitate isolation of information-processing components of task performance (see Sternberg, 1977b, Chapters, 4, 7 and 8). In analogies, for example, precueing with both zero and two terms has generally been sufficient. In classification and series problems, precueing with zero and three terms has generally been sufficient.

2. Deduction tasks. I have used precueing in the investigation of one deduction task, linear syllogisms, presenting either no premises, just the first premise, or both premises in the first part of a trial, and the full problem in the second part of the trial. In general, though, another method, the method of partial tasks, has been more useful in isolating the components of information processing in deductive reasoning (see Sternberg, in press [a]). In this method, subjects receive either the full task or a partial task on a given trial. Consider for example, the linear syllogism (or three-term series problem). The full task consists of an item such as JOHN IS TALLER THAN PETE; PETE IS TALLER THAN BILL; WHO IS TALLEST? JOHN, PETE, BILL. A partial task can be formed via a two-term series problem, such as JOHN IS TALLER THAN PETE; WHO IS TALLEST? JOHN, PETE. (The ungrammatical superlative form of the question is retained to preserve comparability of format.) This partial task is theorized to require for its solution a subset of the information-processing components involved in solution of the full task. The same principle of task decomposition can be applied to certain forms of categorical syllogisms, for example, ALL B ARE C; ALL A ARE B; Is SOME A ARE C valid? In a partial task, the subject would receive the problem ALL B ARE C; Is SOME B ARE C valid? In one form of conditional syllogism, the subject would receive either a full problem,

IF A THEN ALWAYS B; IF B THEN ALWAYS C; Is IF A THEN SOMETIMES C valid?, or a partial problem, IF A THEN ALWAYS B; Is IF A THEN SOMETIMES B valid?

I have claimed above that decomposition of composite tasks into subtasks is useful in order to permit, in subsequent stages of analysis, isolation of information-processing components that would otherwise be confounded. But the use of subtasks is beneficial in understanding the nature of mental abilities even if no further task decomposition is intended. Through the use of subtasks, the investigator can gain insights into task performance that would be unavailable if only composite tasks were used. Consider two examples.

The first example is from a study of induction. In my initial investigations of analogical reasoning (Sternberg, 1977b), I decomposed the analogies task into four subtasks, using either zero, one, two, or three precues. I then correlated subtask scores (for both the first and second parts of the trial) with scores on standard reasoning tasks of the kinds found in a multitude of intelligence tests. My expectation was that the more information processing the experimental subtask required, the higher would be the correlation between the subtask score and the reasoning task. In fact, the reverse pattern was found for response-time scores on both the first half of the trial and the second half of the trial: Correlations decreased with increased amounts of information processing in the subtasks. The finding proved to be replicable in my own work, and moreover, comparable findings have since emerged both in my laboratory and in those of others, for a variety of tasks (see Sternberg, in press [b]). It is a finding that I and others are still

seeking fully to understand. The finding was counterintuitive, to say the least, and never would have emerged in my initial work had I not decomposed composite task scores into subtask scores.

The second example is from a study of deduction. In the categorical syllogisms task, the theorized components of information processing can be grouped into several, more global stages of information processing, among which are two stages called encoding and combination. The first stage involves encoding of the various possible set relations for a given syllogistic premise. The second stage involves combination of the set relations encoded for the two syllogistic premises. The partial task used in one study of categorical syllogisms (Sternberg & Turner, Note 8) is theorized to involve only the encoding stage, whereas the full task used in this study is theorized to involve both the encoding and combination stages. The separation of stages enabled us to find that almost all errors in syllogistic reasoning originate in the combination rather than the encoding stage. The use of the method of partial tasks thus permits exploration of the proposed global stages of syllogistic reasoning without analysis of the component processes that constitute these stages.

The above examples show that the decomposition of composite tasks into subtasks can tell us more about mental abilities than can the investigation of composite tasks alone, but less than the further breakdown of the subtasks into the component processes used in the subtasks. A second step in the breakdown of task performance, therefore, is the isolation of component processes, the step to which we now turn.

The Level of Information-processing Components

In my schematization of the nature of abilities, the level of the component has been the primary one of interest. Indeed, I have used the term, componential metatheory, to refer to the schematization of the nature of mental abilities, and the term, componential analysis, to refer to the methodology used to fill in the substantive details of the various levels of the schematization (Sternberg, 1977b, 1978). A component information process is an elementary operation that operates upon internal representations of objects or symbols (cf. Newell & Simon, 1972). The process may translate a sensory input into a conceptual representation, transform one conceptual representation into another one, or translate a conceptual representation into a motor output (Sternberg, 1977b).

One thorny problem that inevitably arises is that of what is meant by an elementary operation. I believe that the designation of a component process as elementary is arbitrary, in that it will almost certainly be possible to split a given process into smaller processes that represent ever finer levels of analysis. One's goal, therefore, should be to seek out a level of analysis that is theoretically or practically interesting. The level of the component process is noteworthy precisely because it has been demonstrated to be of both theoretical and practical interest. These demonstrations have taken various forms:

1. Detailed specification of task performance. Once the level of the component process is reached, it is possible to provide a detailed specification of task performance. This specification does not stop with the identification of component processes, but includes (a) identi-

fication of the component processes in task performance, (b) specification of the internal representation(s) of information upon which the component processes act, (c) specification of the strategy or strategies by which different component processes and multiple executions of the same component process are combined, (d) specification of the consistency with which the various strategies are employed by individual subjects, and (e) specification of the duration, difficulty, and probabilities of execution of the various component processes.

2. Framework for analyzing individual differences within and across age levels. The five elements of task performance described above provide a framework for analyzing individual-differences variation both within and across age levels. In the tasks I have investigated to date, most individual differences within age level have arisen from sources (d) and (e) above; individual differences across age levels, however, have been found to arise from all five sources of variation (see Sternberg & Rifkin, in press; Sternberg & Nigro, Note 3).

3. Framework for a subtheory of intelligence. Theoretical analyses of the mental abilities constituting much of what we mean by intelligence may start either with tasks and proceed to the components that result from the analysis of the tasks (as in 1 and 2 above), or they may start with component processes and proceed to the tasks that can be constructed from combining the component processes in various ways. Pursuing this latter route, I have used component processes as the basic unit in the unified componential theory of human reasoning. In the theory, reasoning tasks are arranged hierarchically in terms of the overlap in component processes used to perform various tasks. Tasks at higher levels

of the hierarchy require for their solution various concatenations of the component processes required for the solution of tasks lower in the hierarchy. The hierarchy provides a natural means for organizing the various ways in which component processes can overlap across tasks. Relations among tasks are understood in terms of the overlap in component processes used in their solution.

4. Diagnostic and pedagogic value. By analyzing response-time and error data for individual subjects at the level of the component process, it becomes possible to pinpoint quite precisely the source(s) of particular weaknesses or strengths in global information processing. One need not be satisfied merely to say that a certain subject is a good reasoner or a poor reasoner. The etiology of the strength or weakness can be specified in terms of the five sources of individual-differences variation described above. Moreover, it becomes possible to train subjects in strategies that capitalize upon their particular patterns of strength and weakness. We have found, for example, an aptitude-strategy interaction in the solution of linear syllogisms (Sternberg & Weil, Note 9). These problems may be solved either by a strategy that requires both spatial and linguistic information processing, or by a strategy that requires only linguistic information processing. Subjects who are deficient in spatial visualization abilities relative to linguistic comprehension abilities can be trained to use the component processes and rules for combining these processes that make up the linguistic strategy, and can thereby bypass utilization of the abilities in which they are relatively weak.

5. Isolation of component processes based upon within-task, within-subject data analysis. The componential methodology used in the isolation of component processes cannot be fully explicated here. (See Sternberg, 1977b, for details.) In essence, the method involves the use of multiple regression to predict response-times or error rates for performance on tasks that are structurally manipulated in ways that vary the number of executions of each component process theorized to be involved in task performance. The method of analysis isolates component processes on the basis of within-task, within-subject variation. Since problem solving occurs both within tasks and within individual subjects, the proposed line of approach seems to be a reasonable one. Certain alternative methodologies, however, base their analysis on across-task, across-subject variation. Factor-analytic procedures, for example, generally follow this line of approach, leading one to query whether these procedures are capable of leading one to the component processes used in task solution. Even the most committed of factor theorists have doubted that factor analysis is indeed capable of leading one to these processes (e.g., Thurstone, 1947). Componential procedures therefore seem more suitable for data analysis if one's goal is to understand the component processes that enter into various kinds of problem-solving performance.

To summarize, analysis at the level of the component process seems to provide a desirable supplement to analysis at the levels of the composite task and the subtask, providing information about the nature of mental abilities that cannot be gleaned from either of these latter two levels of analysis, or from factor-analytic methods (which will be discussed further later in the article).

So far, I have described the level of the component process and some advantages of seeking this level, without giving any examples of what the proposed component processes are. I will describe here, therefore, a subset of the component processes that, according to the unified componential theory of human reasoning, forms the building blocks of performance on a variety of reasoning tasks. I will limit the subset to be described to components found in a variety of induction tasks. A further catalogue of components, including ones found in deduction tasks, is presented elsewhere (Sternberg, Guyote, & Turner, in press; Sternberg, Note 1).

Just as the unified componential theory of human reasoning may be viewed as a subtheory of intelligence, so may the proposed theory of inductive reasoning be viewed as a subtheory of the theory of human reasoning. The theory of inductive reasoning is called the IMAJER (pronounced like imager) theory. Its name is an acronym for the six component processes theorized to be involved in a wide variety of induction tasks, and briefly described in Table 1--inference, mapping, application, justification, encoding, and response. The best way to understand the meanings of these component processes is to see how they are used in induction tasks of the sort described earlier in the article.

Insert Table 1 about here

Consider the component processes a subject might use in solving an analogy such as LAWYER : CLIENT :: DOCTOR : (a) MEDICINE, (b) PATIENT. The subject would seem to have to encode the terms of the analogy, translating each stimulus into an internal representation upon which further mental operations can be performed. The subject must also infer the

relation between LAWYER and CLIENT, realizing that someone who seeks out the professional services of a lawyer is referred to as a "client." Next, the subject needs to map the higher-order relation that links the first half of the analogy to the second half. This mapping can be accomplished via the relation between the first and third terms: A LAWYER and a DOCTOR are both professionals who provide professional services to the public. Now, the subject must apply from DOCTOR to either MEDICINE or PATIENT the relation that was inferred from LAWYER to CLIENT, and was then mapped into DOCTOR. Only the answer option PATIENT permits application of the appropriate relation. If the subject does not perceive either answer option as permitting application of an exactly analogous relation, then the subject justifies one of the options as preferred, that is, as permitting application of a relation that is closer to the exactly analogous one than is permitted by the other answer option. Finally, the subject responds with the chosen answer, in this case, b.

Consider next the component processes a subject might use in solving the classification problem LEAF, TRUNK, ROOT, (a) BRANCH, (b) TREE. The subject's task is to decide which answer option belongs with the first three terms. The subject must encode each term of the classification problem. The subject must also infer what property or properties LEAF, TRUNK, and ROOT have in common. Next, the subject must apply the list of properties to BRANCH and TREE, deciding which answer option possesses the appropriate set of properties. If neither option possesses all the properties on the list, then the subjects justifies one option as closer to an ideal option, that is, as possessing more of the critical properties than does the other answer option. Finally, the subject responds

with the chosen answer, in this case, a. Note that this particular variant of the classification problem does not require the mapping operation, although other variants do, for example, variants of the problem in which the subject must decide in which of two classes a single object is more appropriately classified. Mapping is required only when the subject must determine a higher-order relation between two lower-order relations, as in analogies, where the mapping links the relation between the first two terms to the relation between the second two terms.

Consider finally the component processes a subject might use in solving the series completion problem, TRUMAN, EISENHOWER, KENNEDY, (a) JOHNSON, (b) ROOSEVELT. The subject must encode the terms of the problem. The subject must also infer the relation between TRUMAN and EISENHOWER, and then infer the relation between EISENHOWER and KENNEDY. The second inference is restricted, in that it need consist only of a subset (and possibly the full set) of attributes that were inferred between the first two terms: Other possible attributes relating the second and third terms are deemed irrelevant in the context of this problem. Next, the subject attempts to apply from KENNEDY to each of the options JOHNSON and ROOSEVELT the relation that could be successfully inferred both from TRUMAN to EISENHOWER and from EISENHOWER to KENNEDY. If neither answer option permits application of the same list of attributes, the subject justifies one of the answer options as permitting application of a more similar list of attributes. Finally, the subject responds with the chosen answer, in this case, a. Note that this problem, like the classification problem, did not include a mapping

operation, because no higher-order relation was involved. Other forms of series completion problems do include a mapping operation.

Analogy, classification, and series completion are three types of induction problems theorized to require the component processes enumerated by the IMAJER theory to induction; but they are not the only types of problems theorized to require these processes. Other types of problems, such as topological relations (Sternberg, Note 1, Note 4), causal inferences (Sternberg, Note 1; Sternberg & Ross, Note 10), and metaphorical relations (Sternberg, Tourangeau, & Nigro, in press; Nigro & Sternberg, Note 11) are also theorized to require these processes in their solution. The component processes posited by the theory are thus theoretically useful in that they seem to be general across a rather wide variety of inductive reasoning tasks.

Do component processes, the representations upon which they act, and the strategies by which they are combined, represent the "bottom line" in the analysis of mental abilities, or is there some deeper level yet? Since subjects must somehow decide what component processes, strategies, and representations to apply to a given problem situation, it appears that a deeper level of analysis is indeed required. I refer to this deeper level of analysis as the metacomponential level.

The Level of Information-processing Metacomponents

The level of metacomponents deals with what Brown and DeLoache (in press) have referred to as metacognition, or the control an individual has over his or her own cognitive processes. In the memory literature, this level of processing has been studied under the rubric of metamemory (Brown, in press; Flavell & Wellman, 1977),[2] and in the problem-solving

literature, under the rubric of the executive, the homunculus, or of control processes (cf. Reitman, 1965).

The metacomponential level controls what happens at the componential level. Metacomponents are the processes by which subjects determine what components, representations, and strategies should be applied to various problems. They also determine the various rates of component execution (including the decision as to how rate will be traded off for accuracy), and the probabilities that various components will be applied at all in a given situation.

My research to date has not dealt explicitly with the exploration of metacomponents, although because it has become increasingly clear that the metacomponential level cannot be ignored, some of my current research is aimed at exploration of metacomponents. Consider how metacomponents have operated in tasks I have previously investigated.

A finding referred to earlier was the increase in the correlation between response times on analogical reasoning subtasks and reasoning tests as the amount of information processing required by the subtasks decreased. This finding would have been unobservable at the composite-task level. It was observable, but not comprehensible, at the subtask level. When the phenomenon was analyzed at the componential level, it was found to be due to the extremely high correlation of the unanalyzed response component with reasoning. The response component was "unanalyzed" in the sense that its duration was estimated as the "regression constant"--that which was constant across all problem types and was left over after the "regression slopes" were estimated. What operation(s) might be constant across the various problem types, beside the presumably uninteresting process of response? It seems likely that one or more metacomponents were constant across problem types--operations that

determine how analogy problems will be solved (as opposed to operations that actually solve the problems). In order fully to understand how subjects solve analogies, therefore, one must identify the metacomponents as well as the components of solution: The constant component must be further subdivided.

A second finding in my research on analogies, which has also proved to be replicable (Sternberg, 1977a, 1977b; Sternberg & Rifkin, in press), is that better reasoners tend to spend longer in encoding terms of the analogy than do poorer reasoners. This pattern is opposite to that found for other component processes (inference, mapping, application, justification, and response), for which faster execution is associated with higher reasoning ability. An analysis of this phenomenon suggests that understanding of it must be sought at the metacomponential level: Better reasoners seem purposely to spend relatively more time in encoding in order to facilitate subsequent attribute-comparison operations (see Sternberg, 1977b, Chapter 8). A parallel might be drawn to a lending library: Slower and more careful cataloguing of books (encoding of analogy terms) requires a greater initial time investment; but this investment is more than repaid by the more rapid and efficient borrowing and lending (inference, mapping, application, justification) that can later take place because of the more efficient retrieval of sought-after volumes. In this example, then, we see a decision by the subject at the metacomponential level to trade off increased encoding time for decreased times on other component processes.

A third finding in my research on analogies is that older children tend to perform the various component processes of analogical reasoning

more nearly exhaustively than do younger children (Sternberg & Rifkin, in press; Sternberg & Nigro, Note 3). Increased use of exhaustive information processing appears to be a general characteristic of cognitive development (Brown & DeLoache, in press), and another finding from the analogies research suggests at least one reason why. Almost all errors made in analogy solution can be traced to self-terminating component processes, that is, processes that terminate before all relevant attributes have been identified or compared. Thus, the large decrease in error rates that occurs in the analogy solutions of older subjects can probably be traced at least in part to a decision at the metacomponential level to process information more nearly exhaustively.

Comparable metacomponential decisions have been found in the various kinds of deductive reasoning tasks I have studied, and can be found in non-reasoning tasks as well. As the number of such findings increases, it becomes increasingly evident that attributions to the "homunculus" and to the "executive" are inadequate to a comprehensive understanding of the nature of mental abilities. We need to start "unpacking" what has been confounded with components and especially the constant in our equation (both literally and figuratively): the metacomponential processes that are responsible for the solution of problems in an intelligent way. I have been as guilty as anyone else (or more so) in packing these processes into the components and especially the constant component. But research findings such as the ones cited above have forced my hand and guided some of my current research toward psychological phenomena that now seem more fundamental than some of those I have studied at the

componential level. But isn't that the function research findings are supposed to serve?

An Alternative Perspective on the Four Levels

No mention has been made so far of the role of what has been previously a central construct in theories of mental abilities, namely, the factor. Factors have often been viewed as source or latent traits (see, for example, Cattell, 1971; Guilford, 1967)--the underlying dimensions along which individuals differ. I have stated elsewhere why I believe this neither is nor could be the case (Sternberg, 1977b, Chapter 2). In the present framework, factors are viewed quite differently, specifically, as constellations of mental abilities, at whatever level, that are organized by patterns of variation across individuals rather than across tasks. Factors provide a useful way of reorganizing data, at a given level, in order to understand the organization of individual differences at that level; but they do not provide a useful way of penetrating data to a deeper level that enables one to understand the sources of those individual differences. Factors, in other words, provide an alternative perspective on each of the levels of mental ability, without supplying an additional level.

Factor scores derived from factor analysis of composite tasks and subtasks can be understood in much the same way that composite-task and subtask scores can be understood--as combined scores of constellations of components and metacomponents. Factor scores are useful in summarizing performance, because rather than being bound by the constraints of the ways in which the tasks or subtasks are put together (as are task and subtask scores), they are bound by the constraints of individual differences--of how components and metacomponents tend to cluster together in tasks and subtasks. If one or more processes appear together

in an entire set of tasks that is factor analyzed, the result will be a general factor; if they appear together in a subset of the tasks, the result will be a group factor; if they appear together in just a single task, the result will be a specific factor. Thus, because the components of the IMAJER theory of induction appear together in a large variety of induction tasks, they will tend to yield a general, or *g*, factor. In a wider range of tasks, they are more likely to yield a group, or even a specific factor. The *g* factor will probably tend to appear in most factor analyses, however, if the same metacomponents are applicable to each task, as seems likely for the various kinds of tasks used to measure intelligence.

Because components and metacomponents may themselves be correlated across subjects, factor analyses of them may well lead to some sort of interpretable factors. What do these factors represent? Presumably, they represent the correlation--in heredity and experience--with which various abilities at all levels develop. The genes and experiences that lead to the development of individual differences in components and metacomponents, as well as tasks and subtasks, are almost certainly highly overlapping in their occurrences. Thus, one can expect to find correlations across subjects in the basic units of analysis at all four levels of mental ability. These communalities are highlighted, but in no sense caused by, factors.

Summary and Conclusions

Mental abilities can be analyzed at four levels--the levels of tasks, subtasks, components, and metacomponents. Each level of analysis tells us something about the structure and content of the mental abilities

responsible for much of what we refer to as intelligent performance. Deeper levels of analysis are in some ways more interesting than shallower levels of analysis, but they are not a substitute for them. In order fully to understand the nature of mental abilities, one needs to know the composite tasks through which intelligent performance is demonstrated; the subtasks that in combination constitute the composite tasks; the component processes, representations, and strategies used in task and subtask performance; and the metacomponents that control these processes, representations, and strategies. Factors provide a useful alternative way of organizing this information, but do not themselves provide a further level of analysis. They may be viewed as related horizontally, rather than vertically, to each of the levels of analysis.

Surprisingly, our understanding of even the shallower levels of analysis is quite crude. Although many of the tasks believed to reflect intelligent performance (and some of the subtasks that they comprise) have been studied fairly widely, an intelligent taxonomy of these tasks can be formed only after we know the components and metacomponents that enter into them. Similarly, an intelligent taxonomy of components requires understanding of the metacomponents controlling them, and we have almost no understanding of activities at the metacomponential level. A well integrated understanding of all these levels is a long way off, but is actively being sought.

Reference Notes

1. Sternberg, R. J. Toward a unified componential theory of human reasoning (NR 150-412 ONR Technical Report No. 4). New Haven: Department of Psychology, Yale University, April, 1978. Also manuscript submitted for publication, 1978.

2. Sternberg, R. J., & Gardner, M. K. A unified theory of inductive reasoning in semantic space. Manuscript in preparation, 1978.

3. Sternberg, R. J., & Nigro, G. The development of verbal relations in analogical reasoning. Manuscript submitted for publication, 1978.

4. Sternberg, R. J. Components of inductive reasoning. Manuscript in preparation, 1978.

5. Sternberg, R. J. Representation and process in transitive inference. Manuscript submitted for publication, 1978.

6. Sternberg, R. J. A proposed resolution of curious conflicts in the literature on linear syllogistic reasoning (NR 150-412 ONR Technical Report No. 8). New Haven: Department of Psychology, Yale University, June, 1978. Also paper presented at VIIIth International Symposium on Attention and Performance, Princeton, August, 1978.

7. Guyote, M. J., & Sternberg, R. J. A transitive-chain theory of syllogistic reasoning (NR 150-412 ONR Technical Report No. 5). New Haven: Department of Psychology, Yale University, April, 1978. Also paper submitted for publication, 1978.

8. Sternberg, R. J., & Turner, M. E. Components of syllogistic reasoning (NR 150-412 ONR Technical Report No. 6). New Haven: Department of Psychology, Yale University, April, 1978. Also paper submitted for

publication , 1978.

9. Sternberg, R. J., & Weil, E. An aptitude-strategy interaction in the solution of linear syllogisms. Manuscript submitted for publication, 1978.

10. Sternberg, R. J., & Ross, B. Causal inference and classification. Manuscript in preparation, 1978.

11. Nigro, G., & Sternberg, R. J. Component processes in metaphoric comprehension and appreciation. Manuscript in preparation, 1978.

References

Brown, A. L. Knowing when, where, and how to remember: A problem of metacognition. In R. Glaser (Ed.), Advances in instructional psychology. Hillsdale, N J.: Erlbaum, in press.

Brown, A. L., & DeLoache, J. S. Skills, plans, and self-regulation. In R. Siegler (Ed.), Children's thinking: What develops. Hillsdale, N. J.: Erlbaum, in press.

Cattell, R. B. Abilities: Their structure, growth, and action. Boston: Houghton-Mifflin, 1971.

Guilford, J. P. The nature of human intelligence. New York: McGraw-Hill, 1967.

Flavell, J. H., & Wellman, H. M. Metamemory. In R. V. Kail, Jr., & J. W. Hagen (Eds.), Perspectives on the development of memory and cognition. Hillsdale, N. J.: Erlbaum, 1977.

Lord, F. M., & Novick, M. R. Statistical theories of mental test scores. Reading, Mass.: Addison-Wesley, 1968.

Newell, A., & Simon, H. Human problem solving. Englewood Cliffs, N.J.: Prentice-Hall, 1972.

Reitman, W. Cognition and thought. New York: Wiley, 1965.

Sternberg, R. J. Component processes in analogical reasoning. Psychological Review, 1977, 84, 353-378. (a)

Sternberg, R. J. Intelligence, information processing, and analogical reasoning: The componential analysis of human abilities. Hillsdale, N. J.: Erlbaum, 1977. (b)

Sternberg, R. J. Componential investigations of human intelligence. In A. Lesgold, J. Pellegrino, S. Fokkema, & R. Glaser (Eds.), Cognitive

psychology and instruction. New York: Plenum, 1978.

Sternberg, R. J. Isolating the components of intelligence. Intelligence, in press. (a).

Sternberg, R. J. Intelligence research at the interface between differential and cognitive psychology: Prospects and proposals. Intelligence, in press (b).

Sternberg, R. J., Guyote, M. J., & Turner, M. E. Deductive reasoning. In P. Federico, R. Snow, & W. Montague, (Eds.), Proceedings of the conference on aptitude, learning, and instruction: Cognitive process analysis, in press.

Sternberg, R. J., & Rifkin, B. The development of analogical reasoning processes. Journal of Experimental Child Psychology, in press.

Sternberg, R. J., Tourangeau, R., & Nigro, G. Metaphor, induction, and social policy: The convergence of macroscopic and microscopic views. In A. Ortony (Ed.), Metaphor and thought. New York: Cambridge University Press, in press.

Sternberg, R. J., & Tulving, E. The measurement of subjective organization in free recall. Psychological Bulletin, 1977, 84, 539-556.

Stevens, S. S. Mathematics, measurement and psychophysics. In S. S. Stevens (Ed.), Handbook of experimental psychology. New York: Wiley, 1951.

Thurstone, L. L. Multiple factor analysis. Chicago: University of Chicago Press, 1947.

Footnotes

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[1]The views presented in this paper represent a further development of ideas first presented in Sternberg (1977b). These views are not in complete accord with the earlier ones, however, as my ideas regarding the nature of mental abilities have changed over time. In the earlier volume, for example the fourth (metacomponential) level of the theory had not yet appeared.

[2]Metamemory is often used to refer to knowledge about, rather than control of, memory.

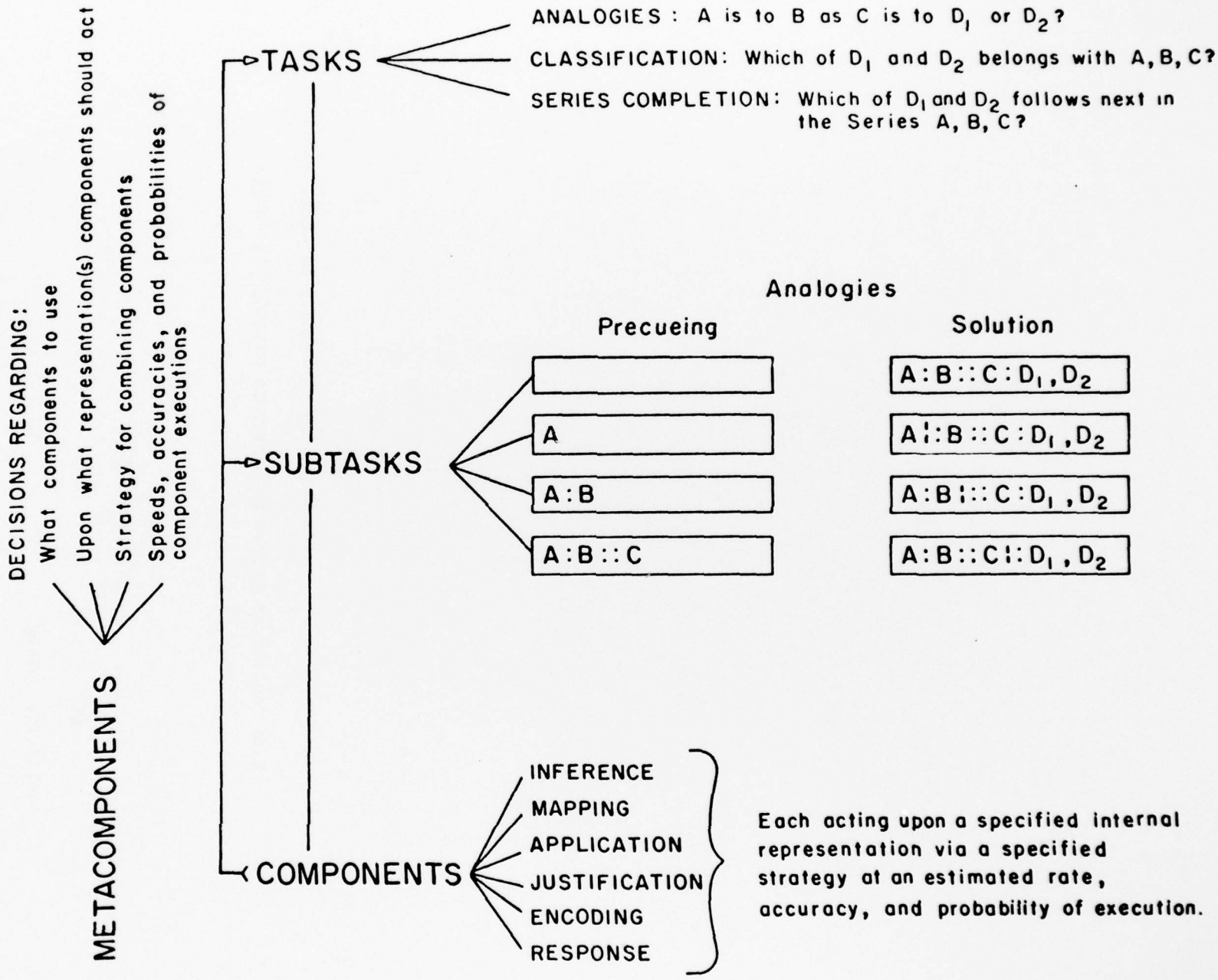
Table 1

Information-processing Components of the EMAJER Theory of Induction

Component	Description
Encoding	Translation of a stimulus into an internal representation upon which further mental operations can be performed
Inference	Discovery of one or more relations between two terms of a problem
Mapping	Discovery of one or more relations between two relations in a problem
Application	Use of one or more previously known or inferred relations in a problem
Justification	Selection of an answer option in problem as preferred but nonoptimal
Response	Communication of an answer to a problem

Figure Caption

Figure 1. Outline of theory of mental abilities, with examples at right of figure.


METACOMPONENTS
DECISIONS REGARDING:
What components to use
Upon what representation(s) components should act
Strategy for combining components
Speeds, accuracies, and probabilities of component executions
TASKS
ANALOGIES : A is to B as C is to D_1 or D_2?
CLASSIFICATION: Which of D_1 and D_2 belongs with A, B, C?
SERIES COMPLETION: Which of D_1 and D_2 follows next in the Series A, B, C?
SUBTASKS
Analogies
Precueing
Solution
A:B::C:D_1, D_2
A!:B::C:D_1, D_2
A:B!::C:D_1, D_2
A:B::C!:D_1, D_2
COMPONENTS
INFERENCE
MAPPING
APPLICATION
JUSTIFICATION
ENCODING
RESPONSE
Each acting upon a specified internal representation via a specified strategy at an estimated rate, accuracy, and probability of execution.

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